THE OSCILLOSCOPE
APPENDIX A

The oscilloscope (scope for short) is the most useful and versatile electronic test instrument. As usually used, it lets you "see" voltages in a circuit as a function of time, triggering on a particular point of the waveform so that a stationary display results. We've drawn a block diagram (Fig. A1) and typical front panel (Fig. A2) to help explain how it works. The scope we will describe is usually called a dc-coupled dual-trace triggered scope. There are special-purpose scopes used for TV servicing and the like, and there are scopes of an older vintage that don't have the features needed for circuit testing.

VERTICAL

Beginning with the signal inputs, most scopes have two channels; that's very useful, since you often need to see the relationship between signals. Each channel has a calibrated gain switch, which sets the scale of VOLTS/DIVISION *on the screen*. There's also a VARIABLE gain knob (concentric with the gain switch) in case you want to set a given signal to a certain number of divisions. Warning: Be sure the variable gain knob is in the "calibrated" position when making voltage measurements! It's easy to forget. The better scopes have indicator lights to warn

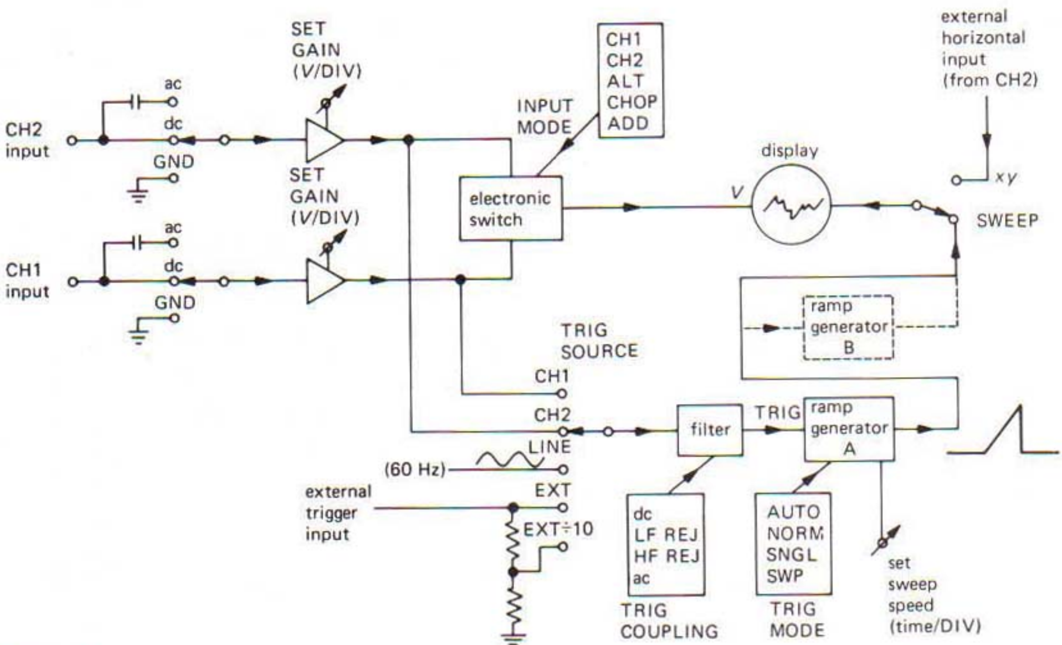

Figure A1

you if the variable gain knob is out of the calibrated position.

The scope is dc-coupled, an essential feature: What you see on the screen is the signal voltage, dc value and all. Sometimes you may want to see a small signal riding on a large dc voltage, though; in that case you can switch the input to ac coupling, which capacitively couples the input with a time constant of about 0.1 second. Most scopes also have a grounded input position, which lets you see where zero volts is on the screen. (In GND position the signal isn't shorted to ground, just disconnected from the scope, whose input is grounded.) Scope inputs are usually high-impedance (a megohm in parallel with about 20pF), as any good voltage-measuring instrument should be. The input resistance of 1.0 megohm is an

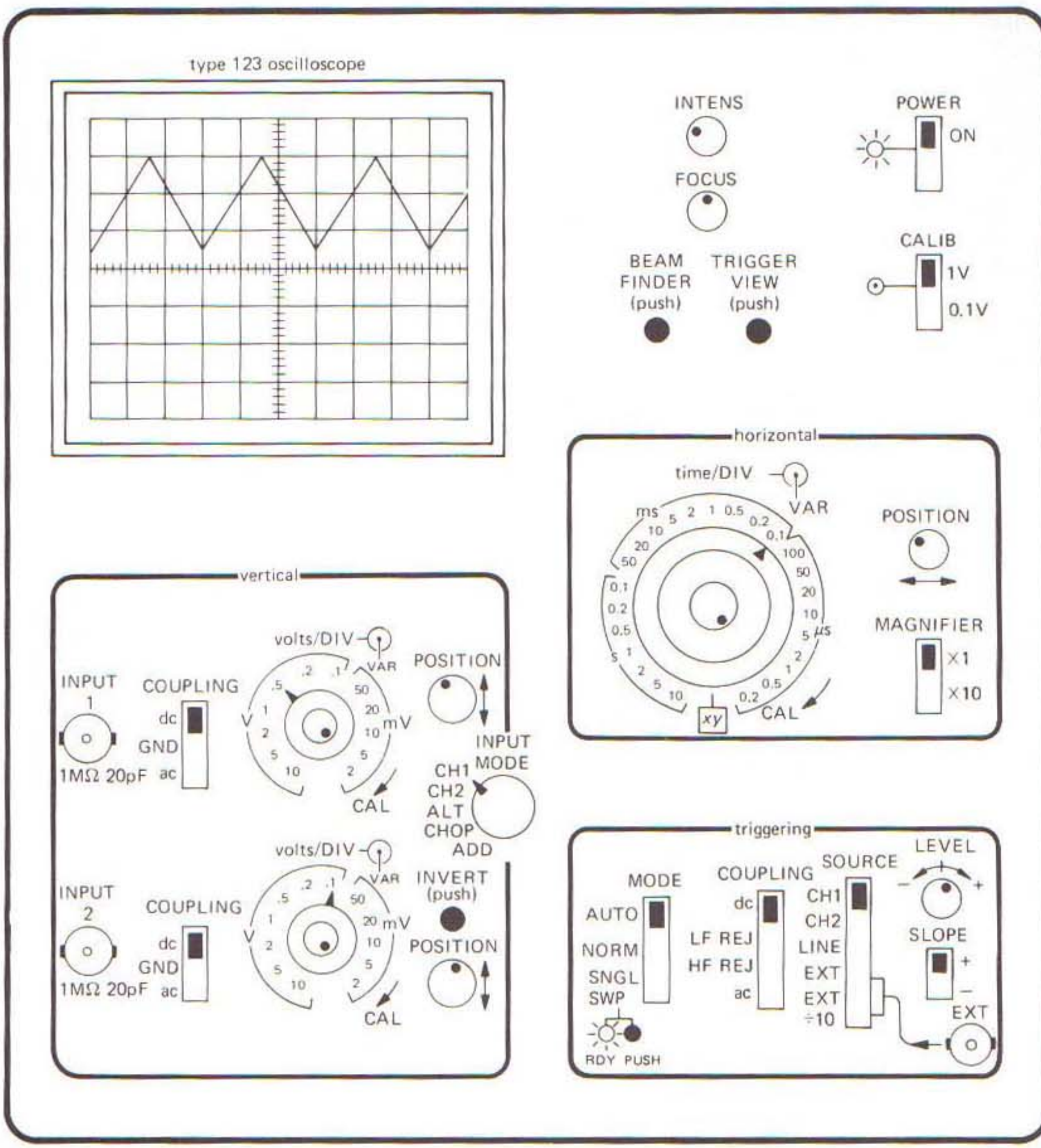

Figure A2

accurate and universal value, so that high-impedance attenuating probes can be used (as will be described later); unfortunately, the parallel capacitance is not standardized, which is a bit of a nuisance when changing probes.

The vertical amplifiers include a vertical POSITION control, an INVERT control on at least one of the channels, and an INPUT MODE switch. The latter lets you look at either channel, their sum (their difference, when one channel is inverted), or both. There are two ways to see both: ALTERNATE, in which alternate inputs are displayed on successive sweeps of the trace; CHOPPED, in which the trace jumps back and forth rapidly (0.1–1MHz) between the two signals. ALTERNATE mode is generally better, except for slow signals. It is often useful to view signals both ways, to make sure you're not being deceived.

HORIZONTAL

The vertical signal is applied to the vertical deflection electronics, moving the dot up and down on the screen. The horizontal sweep signal is generated by an internal ramp generator, giving deflection proportional to time. As with the vertical amplifiers, there's a calibrated TIME/DIVISION switch and a VARIABLE concentric knob; the same warning stated earlier applies here. Most scopes have a 10 × MAGNIFIER and also allow you to use one of the input channels for horizontal deflection (this lets you generate those beloved but generally useless "Lissajous figures" featured in elementary books and science fiction movies).

TRIGGERING

Now comes the trickiest part: triggering. We've got vertical signals and horizontal sweep; that's what's needed for a graph of voltage versus time. But if the horizontal sweep doesn't catch the input signal at the same point in its waveform each time (assuming the signal is repetitive), the display will be a mess – a picture of the input waveform superimposed over itself at different times. The trigger circuitry lets you select a LEVEL and SLOPE (+ or −) on the waveform at which to begin the sweep. You can see from the front panel that you have a number of choices about trigger sources and mode. NORMAL mode produces a sweep only when the source selected crosses through the trigger point you have set, moving in the direction (SLOPE) you have selected. In practice, you adjust the level control for a stable display. In AUTO the sweep will "free run" if no signal is present; this is good if the signal sometimes drops to small values, since the display won't disappear and make you think the signal has gone away. It's the best mode to use if you are looking at a bunch of different signals and don't want to bother setting the trigger each time. SINGLE SWEEP is used for nonrepetitive signals. LINE causes the sweep to trigger on the ac power line, handy if you're looking at hum or ripple in a circuit. The EXTERNAL trigger inputs are used if you have a clean signal available at the same rate as some "dirty" signal you're trying to see; it's often used in situations where you are driving some circuit with a test signal, or in digital circuits where some "clock" signal synchronizes circuit operations. The various coupling modes are useful when viewing composite signals; for instance, you may want to look at an audio signal of a few kilohertz that has some spikes on it. The HF REJ position (high-frequency reject) puts a low-pass filter in front of the trigger circuitry, preventing false triggering on the spikes. If the spikes happen to be of interest, you can trigger on them instead in LF REJ position.

Many scopes now have BEAM FINDER

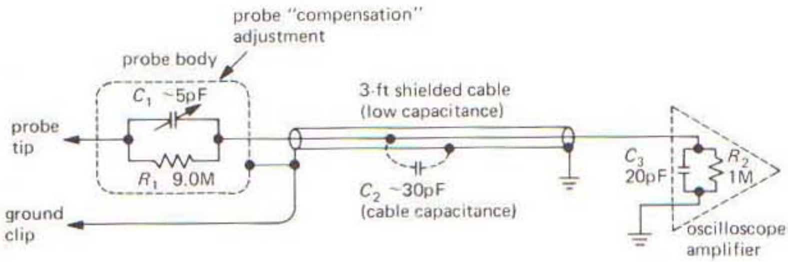

Figure A3

and TRIGGER VIEW controls. The beam finder is handy if you're lost and can't find the trace; it's a favorite of beginners. Trigger view displays the trigger signal; it's especially handy when triggering from external sources.

HINTS FOR BEGINNERS

Sometimes it's hard to get *anything* to show on the scope. Begin by turning the scope on; set triggering for AUTO, DC COUPLING, CH 1. Set sweep speed at 1ms/div, cal, and the magnifier off (×1). Ground the vertical inputs, turn up the intensity, and wiggle the vertical position control until a horizontal line appears (if you have trouble at this point, try the beam finder). Warning: Some scopes (the popular Tektronix 400 series, for example) don't sweep on AUTO unless the trigger level is adjusted correctly. Now you can apply a signal, unground the input, and fiddle with the trigger. Become familiar with the way things look when the vertical gain is far too high, when the sweep speed is too fast or slow, and when the trigger is adjusted incorrectly.

PROBES

The oscilloscope input capacitance seen by a circuit under test can be quite high, especially when the necessary shielded connecting cable is included. The resulting input impedance (1 megohm in parallel with 100 picofarads or so) is often too low for sensitive circuits and loads it by the usual voltage divider action. Worse yet, the capacitance may cause some circuits to misbehave, even to the point of going into oscillation! In such cases the scope obviously is not acting like the "low-profile" measurement instrument we expect; it's more like a bull in a china shop.

The usual solution is the use of high-impedance "probes." The popular 10× probe works as shown in Figure A3. At dc it's just a 10× voltage divider. By adjusting C_1 to 1/9th the parallel capacitance of C_2 and C_3, the circuit becomes a 10× divider at all frequencies, with input impedance of 10 megohms in parallel with a few picofarads. In practice, you adjust the probe by looking at a square wave of about 1kHz, available on all scopes as CALIB, or PROBE ADJ, setting the capacitor on the probe for a clean square wave without overshoot. Sometimes the adjustment is cleverly hidden; on some probes you twist the body of the probe and lock it by tightening a second threaded part. One drawback: A 10× probe makes it difficult to look at signals of only a few millivolts; for these situations use a "1× probe," which is simply a length of low-capacitance shielded cable with the usual probe hardware (wire "grabber," ground clip, handsome knurled handle, etc.). The 10× probe should be the standard probe, left connected to the scope, with the 1× probe used when necessary. Some probes feature a convenient choice of 1× or

10× attenuation, switchable at the probe tip.

GROUNDS

As with most test instruments, the oscilloscope input is referred to the instrument ground (the outer connection of the input BNC connectors), which is usually tied electrically to the case. That, in turn, connects to the ground lead of the ac power line, via the 3-wire power cord. This means that you cannot measure voltages between the two arbitrary points in a circuit, but are forced to measure signals relative to this universal ground.

An important caution is in order here: If you try to connect the ground clip of an oscilloscope probe to a point in the circuit that is at some voltage relative to ground, you will end up shorting it to ground. This can have disastrous consequences to the circuit under test; in addition, it can be downright dangerous with circuits that are "hot to ground" (transformerless consumer electronics like television sets, for example). If it is imperative to look at the signal between two points, you can either "float" the scope by lifting the ground lead (not recommended, unless you know what you're doing) or make a differential measurement by inverting one input channel and switching to ADD (some plug-in modules permit direct differential measurements).

Another caution about grounds when you're measuring weak signals or high frequencies: Be sure the oscilloscope ground is the same as the circuit ground where you're measuring. The best way to do this is by connecting the short ground wire on the probe body directly to the circuit ground, then checking by measuring the voltage of "ground" with the probe, observing no signal. One problem with this scheme is that those short ground clips are usually missing, lost! Keep your probe accessories in a drawer somewhere.

OTHER SCOPE FEATURES

Many scopes have a DELAYED SWEEP that lets you see a segment of a waveform occurring some time after the trigger point. You can dial the delay accurately with a multiturn adjustment and a second sweep-speed switch. A delay mode known as A INTENSIFIED BY B lets you display the whole waveform at the first sweep speed, with the delayed segment brightened; this is handy during setup. Scopes with delayed sweep sometimes have "mixed sweep," in which the trace begins at one sweep speed, then switches to a second (usually faster) speed after the selected delay. Another option is to begin the delayed sweep either immediately after the selected delay or at the next trigger point after the delay; there are two sets of trigger controls, so the two trigger points can be set individually. (Don't confuse delayed sweep with "signal delay." All good scopes have a delay in the signal channel, so you can display the event that caused the trigger; it lets you look a little bit backward in time!) Many scopes now have a TRIGGER HOLDOFF control; it inhibits triggering for an adjustable interval after each sweep, and it is very useful when viewing complicated waveforms without the simple periodicity of a sine wave, say. The usual case is a digital waveform with a complicated sequence of 1's and 0's, which won't generate a stable display otherwise (except by adjustment of the sweep-speed vernier, which means you don't get a calibrated sweep). There are also scopes with a "storage" that let you see a nonrepetitive event, and scopes that accept plug-in modules. These let you do just about anything, including display of eight simultaneous traces, spectrum analysis, accurate (digital) voltage and time measurements on waveforms, etc. Digital-storage analog oscilloscopes of a new generation are becoming popular; they let you catch a one-shot waveform, and even let you look backward in time (before the trigger event).